IV. "On the Structure, Physiology, and Development of *Antedon* (*Comatula*, Lamk.) *rosaceus*." By William B. Carpenter, M.D., F.R.S. Received December 16, 1875.

[Plates 8, 9.]

When, in 1865, I communicated to the Royal Society the First Part of a Monograph on the Anatomy, Physiology, and Development (excluding the earliest stages previously described by Prof. Wyville Thomson) of an animal which might be regarded—except in certain comparatively unimportant particulars—as a type-form of the whole Crinoidal series, I had so nearly concluded my investigation of the subject of it, that I fully contemplated the presentation of the Second and concluding part in the course of a year or two. Uncertain health, however, interfered with its completion in the first instance; and my spare time has since then been so far taken up by the various inquiries that have arisen out of the Deep-Sea researches which I prosecuted in the vacations of 1868 and three following years, that I have found myself quite unable to resume the study of *Antedon*. Thus it comes to pass that, though I have now had by me for a period of ten years the results of my previous labours, as presented in several hundred preparations, with a series of most admirable drawings executed by Messrs. George West and A. Hollick, illustrating almost every point of primary importance not only in its structure, but also in the history of its development from nearly the earliest Pentacrinoid stage, all this material has remained unpublished; for I have felt that the completion of my Monograph in a manner worthy of its subject required that certain obscurities should be dissipated and certain gaps filled up; and it now, also, becomes desirable that the Histology of this type should be more fully elucidated by the aid of modern appliances, and that the earliest phases of its Development should be thoroughly reinvestigated. I especially desire to ascertain whether the free-swimming larva (or pseudembryo) has a *Gastræa* stage, and to follow out the derivation of the gastric and perivisceral cavities of the Pentacrinoid, and of its original tentacular system, from the structures of the pseudembryo—points on which Prof. Wyville Thomson's Memoir, admirable as it is, does not enlighten us. This stage of the history has been subsequently studied by a most able observer, Herr Metschnikoff*; and the conclusions he has arrived at in regard to the origin of the tentacular system I find to be essentially accordant with those which I had drawn from my own researches on a later stage.

In the autumn of the year 1868 I had the pleasure of a visit from Dr. Semper, who had then newly returned from a long residence in the Philippine Islands, where he had not only made a large collection of different species of *Antedon* (including many new ones of singular con-

* Bulletins de l'Acad. Impér. de St. Pétersb. 1870, pp. 508, 509.

formation), but had also investigated their structure to an extent sufficient to enable him to recognize the erroneousness of many of the statements put forth by Prof. J. Müller in his celebrated Memoir of 1841, 'Ueber den Bau des *Pentacrinus Caput Medusæ*,' which has been the principal authority as to the structure of the CRINOIDEA for all subsequent writers of zoological text-books. I then placed before Dr. Semper not only the already published First part of my Memoir, but also the materials I had collected for the Second; and finding that my main conclusions agreed completely with those at which he had arrived, he most kindly offered to hold back the publication of his own views until I should have given mine to the world. Having been subsequently appointed to the Chair of Zoology in the University of Wurzburg, Prof. Semper has of course taught to his students what both he and I regarded as the truth of many things erroneously viewed by J. Müller; and another investigator, M. Edmund Perrier*, having in the meantime entered the field, and reproduced some of Müller's errors, Prof. Semper has thought it right to give a wider publicity to his convictions on the subject, which my own protracted delay fully justified him in doing. "In the year 1868," he says, "I was intending to publish a short memoir on that which I had found, when, becoming acquainted in London with Dr. Carpenter, I was delighted to learn that that able observer had obtained exactly the same results on European as I on Philippine *Comatulæ*. In the expectation that the English investigator would soon publish his already prepared work on the Crinoidea, I deferred till now the communication of the results of my examination: but since, after five years waiting, there is imminent risk that from my lectures the results of Carpenter's and my own toilsome investigations may somehow find their way into publicity, I hold that the moment has arrived to break the silence I have hitherto kept"†. For the same reason I think it desirable to place on record without further delay the general results of my own investigations, with such illustrations as may render my descriptions intelligible—though I have reason to hope that the time may not be far distant when I may be able to present to the Royal Society the Second Part of my Memoir, giving with the First such a detailed account of the Structure and Life-history of this type as may serve as a basis for the description of the Pedunculate Crinoids known as living types. Of these I have already examined two of the West-Indian species of *Pentacrinus*, with the *P. Wyville-Thomsoni* (of which several specimens were obtained

* Archives de Zoologie Expérimentale, tom. ii. 1873, pp. 29–86.—This observer has confined himself to the study of the arms, examining their terminations as transparent objects. In this manner he has added much to our knowledge of their Histology; but, through not having examined *transverse sections* of the arms and pinnules, he has not only failed to recognize the true tentacular canal, but has been led to affirm that there is only one canal-system in the brachial apparatus.

† Ann. & Mag. Nat. Hist. Sept. 1875, p. 202.

in the second 'Porcupine' Expedition off the coast of Portugal); and I have further information to give on the *Rhizocrinus Lofotensis* (Sars), the recent type of the Apiocrinida. These, with the numerous other Crinoids collected during the 'Challenger' Expedition, will doubtless furnish ample materials for such an elucidation of the Structure and Life-history of this most interesting group as may afford a secure basis for the scientific study of its great Palæontological series.

Anatomy.

Calyx and its Contents.

Calyx.—The shallow basin (Phil. Trans. 1866, plate xxxii. fig. 2) which holds the central portion of the visceral apparatus is formed not only by the first, second, and third Radials, but also by the first and second pairs of Brachials, together with the basal segments of the pinnules borne by the second—these portions of the calcareous skeleton being so connected laterally by intervening perisome as to complete the wall of the concavity. This concavity is lined by a smooth membrane, which may be conveniently and, I think, correctly termed *peritoneum*, as it forms the immediate boundary of the perivisceral cavity or *cœlom*. The calyx is shut in above by the perisome of the oral disk, which is lined by a continuation of the peritoneum; and this is also reflected over the "visceral mass" which occupies the cavity thus enclosed. This "visceral mass" is a compact lenticular body, which includes the whole digestive and sanguigenous apparatus, with the central portion of the circulatory and respiratory systems and the prolongation of the axial cord of the stem, from which is given off the generative *rachis* that passes into each arm; but it does not include either what I regard as the nervous centre or the generative organs (testes or ovaries)—the former being contained in the cavity of the centro-dorsal basin which underlies the calyx, while the latter, as has long been known, are distributed through certain pinnules of the arms.

Oral Disk.—The membranous perisome which forms the oral disk is continuous with that which is prolonged over the oral surface of the arms and pinnules, and which also dips down between the basal segments of the arms to complete the cavity of the calyx. Towards the mouth (Phil. Trans. 1866, plate xxxii. fig. 3), which is situated in its centre, five radial furrows converge, each of them formed by the union of two converging brachial furrows. The distance from the mouth at which thi union takes place is by no means constant; and I attach little value as a specific character to variations in the distribution of these furrows. The floor of each consists of what appears to be a layer of columnar epithelium, which I believe to be ciliated. Its sides are formed by elevated ridges of the perisome, each of which is scolloped at its edges so as to form a row of minute valvules (the "crescentic leaves" of

Wyville Thomson), from within every one of which there rises a pair of non-extensile tubular tentacles. Each pair of tentacles springs from a base common to it with the leaflet; and this base communicates by a single oval orifice with the *tentacular canal*, which lies immediately beneath the epithelial floor of the furrow. (This is quite distinct from the "tentacular canal" of previous authors, which lies below it and has no connexion whatever with the tentacles, and which I term the *subtentacular canal.*) The convergence of the five radial furrows towards the mouth gives it when viewed from above somewhat the form of a five-rayed star, the adjacent rays being separated by rounded projecting lobes of perisome (Plate 8. fig. 2, *m*, *m*), beneath which (as shown at *a*, figs. 2, 3) is situated the true mouth surrounded by a thickened annular lip. Within each of the five lobes of perisome there arise from the annular lip, by separate bases, a series of from eight to ten thick-walled tentacles, each of which has its own orifice of communication with the interior of the oral ring.

The true *tentacular canals* are the representatives of the "radial vessels" described by Prof. Wyville Thomson, in his account of the Pentacrinoid larva, as extensions of the oral-ring canal, which, as will hereafter appear (p. 227), is a derivative of the perivisceral cavity, marked off from it by threads of connective tissue, as shown at *rc*, figs. 10, 11. In the adult *Antedon*, however, the thickened annular lip which surrounds the mouth does not contain any distinct ring-canal, its original cavity having been almost entirely filled up by threads and bands of connective tissue, and by a set of cæcal tubuli, as to the precise relations of which I am at present in doubt. But the true tentacular canals still pass towards it, and seem to lose themselves in what may be called its "interspace system," this being continuous with that which has come almost entirely to occupy (as shown in fig. 3, *k*) the portion of the perivisceral cavity that originally lay open within the intestinal coil.

The *subtentacular canals*, on the other hand, radiate continuously from the neighbourhood of the mouth to the bases of the arms, each of the five radial trunks divaricating into two; but they do not give off any branches or extensions whatever until they reach the arms, where alternating lateral extensions pass into the pinnules. On approaching the mouth, where the oral perisome becomes continuous with the lining of the œsophagus, these canals dip downwards into the "visceral mass," as was long since described by Heusinger*, though he did not trace their further course in its interior. I shall presently show that they there all become continuous (as at *l*, fig. 2) with the single "axial canal" (*g*), which passes downwards towards the centre of the dorsal surface of the visceral mass, and, through that canal, with the deeper or dorsal portion of the perivisceral cavity. And the history of the development of the subtentacular canals (Plate 9. fig. 12, *stc*) plainly shows that they too are derivatives from the upper or oral portion of the same cavity, which the progressive increase

* Zeitschrift für organ. Physik, Bd. iii. (1829), p. 366.

of the visceral mass, and the formation of membranous adhesions (as at *m*, fig. 12) between the apposed surfaces of its peritoneal covering and of the peritoneal lining of the calyx, separate into an upper and a lower portion, whose communication with each other is maintained by the axial canal.

The oral perisome is perforated in the spaces between the radial furrows (especially near the angles formed by their junction in the mouth) by numerous minute pores surrounded by ciliated epithelium, whose cilia I have seen in extremely active movement, apparently inwards. These are the orifices of funnel-shaped canals, which first pass vertically through the perisome, and then contract and take an oblique direction, opening (I believe) into a system of sinuses, which are left by the incomplete adhesion of the peritoneum covering the upper surface of the visceral mass to that which lines the under surface of the oral perisome. If this be the case, they obviously establish a direct connexion between this limited portion of the perivisceral cavity and the medium inhabited by the animal; and the water thus introduced probably serves a respiratory purpose*.

Perivisceral Cavity.—The adhesion of the under surface of the oral perisome to the upper surface of the visceral mass is so close that they can only be detached by tearing, after both have been hardened in spirit. The peritoneal covering of the lower or dorsal surface of the visceral mass, on the other hand, is but slightly adherent to the opposite peritoneal surface lining the deeper part of the concavity of the calyx, although usually in close contact with it; and thus, when the periphery of the oral disk has been cut through, the visceral mass adherent to its lower surface may be lifted entire out of the calyx, without rupture of any thing but a pedicle (*h*, figs. 2, 3) which passes up as a continuation of the original Crinoidal axis, through the "rosette" (Part I. § 35) formed by the metamorphosis of the original Basals. Hence it often happens that, through the tearing of their oral perisome, which is very soft in the living state, specimens of *Antedon* come up in the dredge completely eviscerated; and I have strong evidence that even this loss may be repaired (as the like evisceration is said to be in *Holothurida*) by the production of a new visceral mass from the "axial prolongation."

Although the visceral mass so nearly fills the cavity of the calyx that scarcely any space exists between their apposed peritoneal surfaces, yet the existence of a true peritoneal cavity becomes obvious at the bases of the arms; for it is there prolonged, in each arm, into an extension (*cc*, fig. 7) which forms a canal that underlies the subtentacular canal (*stc*) proceeding into it from the oral disk; and, like that canal, it not only passes along the whole length of each arm, but also gives off lateral extensions (*d d*) that proceed to the extremities of the pinnules. This canal,

* These canals have been noticed by Grimm (Bulletins de l'Acad. Impér. de St. Pétersb. 1872, pp. 3–8); but he has not been able to trace their internal connexions. By Perrier (*loc. cit.*) they are described as cæca.

as being a direct extension of the body-cavity or *cœlom*, I term the *cœliac* canal.

Visceral Mass.—The "visceral mass" primarily consists of an alimentary canal (not distinctly differentiated into œsophagus, stomach, and intestine), which makes about one fourth more than a single round turn upon itself (*b c d*, fig. 1). From the central mouth this canal at first passes obliquely downwards (*b*, figs. 2, 3), then changes its direction to the horizontal, and, after making somewhat more than a complete circuit, turns upwards again (at *d*, fig. 1) towards the oral disk, to terminate in a vent which projects upwards from its surface between two of the radial furrows, the terminal portion of the alimentary canal being separated from the cavity of the vent by a valvular projection of its lining membrane.

The membranous wall of the alimentary canal may be called its mucous lining. It is somewhat rugose in the first or oblique part of the canal (*b*, fig. 2); whilst in the horizontal coil it is nearly smooth on the peripheral side, but deeply plicated on the central side (fig. 1), there forming, with its epithelial (?) covering, a sort of glandular mass*, the projection of which into the canal considerably narrows it, as shown at *e*, fig. 2. The whole smooth inner surface of the mucous lining (*b*, *c*, fig. 1) is covered with a layer of a yellow substance, which is so soft in the living state that it is difficult to separate it for microscopic examination, but which, when hardened in spirit, readily detaches itself from the subjacent membrane in large flakes, which are so opaque as not to be readily examined minutely. The appearances presented by thin sections of this layer, however, dispose me to think that it may be regarded as a columnar epithelium imperfectly differentiated into cells; and it can scarcely be doubted that the portion of it forming the large gland-like projection just alluded to has an hepatic function. The projecting edges of its plicated surface are fringed with long cilia, whose function is obviously to produce an indraught into the mouth, and to propel the ingested matter along the canal.

The exterior of the mucous wall of the alimentary canal is not in immediate contact with its peritoneal covering; but a continuous space is left between them, which is everywhere traversed by lamellæ of connective tissue passing between the apposed surfaces. This, which I shall call the *intramural* space, is much more distinct in some varieties of *Antedon rosaceus* than it is in others—the Lough Strangford variety presenting it in the most strongly marked degree, while in the Plymouth specimens the two membranes approximate each other much more closely, the Clyde variety, which is the one I have most studied, holding an intermediate position in this particular.—The like differ-

* A section of this portion very closely resembles the *arbor vitæ* of the cerebellum, the grey substance being represented by the yellow epithelial layer, and the white by the plications of the mucous membrane and the sinuses which they enfold.

ence presents itself in the amount and openness of the "interspace system" to be presently noticed.

The double wall of the alimentary canal is strengthened by the interposition of discoidal calcareous plates; and it is the complex plication of the wall on the central side of the canal, and the consequent piling-up of numerous layers of these disks, which forms the vertical *columella*, erroneously likened by some writers to the sand-canal of Starfish. Besides these disks, there are occasionally to be found minute calcareous spines projecting from the inner surface into the cavity of the alimentary canal, as if they were pegs whereon to hang the epithelial layer.

The interior of this *columella* is traversed by a canal (*g*, figs. 1, 2), which constitutes a most curious feature in the structure of the visceral mass. When the visceral mass has been turned out of the calyx, its lower surface shows a minute pore nearly in its centre; which pore, partly occupied (and often concealed) by the pedicle already spoken of (*h*, figs. 2, 3), is the orifice of communication between the deeper portion of the perivisceral cavity and the "axial canal," which is simply a "survival" of what was originally the part of that cavity segregated from the rest by the winding of the horizontal extension of the alimentary canal round its stomach. The axial canal at first passes upwards almost along the central axis (figs. 2, 3) of the lenticular visceral mass; but as soon as it meets the obliquely descending commencement of the alimentary canal, it too becomes somewhat oblique, lying in close contiguity to the exterior of the digestive cavity. Before, however, it reaches the oral surface of the visceral mass, it subdivides irregularly into five branches, which embrace the œsophageal part of the alimentary canal, and there become continuous, as I have already mentioned, with the five radial canals that lie beneath the tentacular canals of the oral disk, one of which is seen in transverse section at *l*, fig. 1, and others at *i*, *k*. Thus, through the subdivision of the five radial canals of the disk into the ten brachial canals, each of which gives off lateral branches that proceed to the extremities of the pinnules, there is a continuous canal-communication from the axial canal, and hence from the deeper part of the perivisceral cavity through the entire apparatus of arms and pinnules. But the axial canal is also in relation with the wall of the alimentary canal; for between the plications of the inner or central side of the latter there is a very extensive system of irregular passages or interspaces (*k*, fig. 3), which open into the axial canal; and it can scarcely be doubted that these serve, like the mesenteric vessels of higher animals, to receive the nutritive fluid which has transuded through the wall of the alimentary canal, first through the mucous lining into the intramural space, and thence through its peritoneal covering into the perivisceral cavity and its derivations.

Cavity of the Centro-dorsal Basin.—In my previous Memoir I fully described the "centro-dorsal" basin-shaped plate whereon rests the circlet of first Radials, whilst from its free or dorsal surface extend the

clusters of prehensile cirrhi that functionally replace the Crinoidal stem, though homologically they correspond to the nodal verticils of cirrhi borne by the stem of *Pentacrinus*, which themselves take on the prehensile function when, as not unfrequently happens, this stem breaks off just beneath the nodal segment. And I further showed that in the early Pentacrinoid stage of *Antedon* the centro-dorsal segment is not distinguished from the ordinary segments of the stem, and that its enlargement commences with the development of the cirrhi, of which there is at first only a single whorl, but of which two complete verticils at least are present when the young *Antedon* drops off the stem. Again, I showed that in the early Pentacrinoid stage the Basals, not the first radials, rest upon the centro-dorsal segment; and I pointed out how, with the metamorphosis of the circlet of basals into the "rosette," and the progressive enlargement of the centro-dorsal plate, the first radials come to form the central basis of the calyx, resting on the infolded lip of the centro-dorsal. I refer to this now, because it helps greatly in the comprehension of the real import of the curious organ contained within the centro-dorsal basin of the adult *Antedon*; for there is no such basin in the Pedunculate Crinoids, whose calyx rests upon the uppermost segment of the stem, which segment, instead of being the largest, is the smallest, being the latest formed, while the basis of the calyx is formed by the thickened and solidified Basals. Hence it seems clear that the extraordinary development of the highest segment of the stem into the centro-dorsal basin, which is characteristic of the mature *Antedon*, is connected with the multiplication of the prehensile cirrhi which extend themselves from its dorsal surface. The number of these cirrhi, as I formerly showed, is very variable; and I gave reasons for the belief that there is a successional production and exuviation of these appendages, at any rate during the period of growth.

When, by the action of dilute acid, the calcareous network of the centro-dorsal plate has been dissolved, so as to give access, by dissecting away its soft animal basis, to the contents of the cavity, we find it to be almost entirely occupied (as seen at *g*, fig. 3) by a curious hollow, slightly pentangular organ (figs. 4, 5), which was described by Müller as a single-chambered heart. From the angles of the lower or dorsal part of this organ there proceed numerous slender cords (*l*, fig. 2), which pass through the calcareous wall of the centro-dorsal basin into the cirrhi; whilst from the upper part of its peripheral wall are given off five large radiating cords (fig. 3, *l*, *m*), which pass upwards and outwards through the canals formed by the inflexions of the "rosette," each then divaricating into two branches, which enter the two adjacent orifices on the internal face of each pair of first radials, as described in my former Memoir. All these cords were described by Müller as vessels; I am satisfied, however, that they are not tubular, but solid.—On making a transverse section of the hollow organ it is found to contain five chambers

(fig. 4), clustered like the carpels of an orange round a central axis; and near this axis each chamber seems to communicate on its ventral aspect with the surrounding space (an extension of the perivisceral cavity) by a minute orifice (*d*) in its wall. Within the dorsal portion of this organ, lying at the bottom of the centro-dorsal basin, there is a succession of verticils of five triangular leaflets (fig. 5, *a*), increasing in size from below upwards, from the extremities of some of the upper of which leaflets issue groups of three diverging cords that proceed to the cirrhi. I can scarcely doubt that these verticils mark the origins of the earlier cirrhal cords from the Crinoidal axis; and this obviously suggests that the five-chambered organ is itself only another and larger verticil, which has come, by the formation of ventricular cavities in its substance (analogous to the lateral ventricles of the brain), to occupy the whole cavity of the enlarged centro-dorsal basin.

This view, which deprives the chambers of the five-chambered organ of any special physiological significance, is confirmed by what I have ascertained of the structure of the Crinoidal axis which occupies the interior of the stem of the true *Pentacrinus.* This has a central portion quite distinct from the peripheral portion, which forms a cylindrical sheath around it. It is from the cylindrical sheath that at every node of the stem there pass off five cords into the whorls of cirrhi or "auxiliary side arms;" and at every node there is a slight dilatation of the cylinder, which is caused, not by a thickening of the substance of the axis, but by a separation between its central and its peripheral portions—foreshadowing the great ventricular dilatation just described at the summit of the axis of *Antedon.* In *Pentacrinus,* which has no cirrhi attached either to the uppermost part of the stem or to the base of the calyx, there is neither enlarged centro-dorsal cavity nor special dilatation of the Crinoidal axis.

The divaricated cords which enter the First Radials form a sort of "Circle of Willis" within the system of canals completed by their lateral adhesion, as described in my former Memoir (§§ 34, 77); and from this circle there issue five *radial cords,* which speedily divaricate into ten *brachial cords* that pass continuously through the *centra* of the segments of the arms.

This apparatus (consisting of the outer cylinder of the Crinoidal stem, of the five-chambered central organ formed by the dilatation of that axis within the centro-dorsal basin, and of the cords proceeding from it to the arms and cirrhi) I regard as the central portion of a *nervous system;* and I shall hereafter draw what seem to me conclusive proofs that such is its character, both from the distribution of branches of the brachial cords to the muscles of the arms, and from the effect of irritation of the central organ in the living animal, even after its complete evisceration, in causing the sudden and general contraction of those muscles (p. 226).

Axial Prolongation.—I now follow the course of the central or medullary portion of the Crinoidal axis, which passes continuously up-

wards through the middle of the quinquelocular dilatation of its cortical cylinder (as shown at *g*, *h*, fig. 3), just as in a flower the axis which forms the style of a multilocular ovary passes upwards through the midst of the carpels which are clustered around it. In the upward course of this "axial prolongation," as it may be provisionally termed, it first passes through the central aperture of the "rosette," and then through the vertical canal which is left by the truncation of the wedge-like First Radials, thus reaching the base of the cavity of the calyx, and constituting the "pedicle," of which I have already spoken, as the chief attachment existing between the basal (or dorsal) surface of the lenticular visceral mass and the concavity of the calyx. This "pedicle" (*h*, fig. 2) enters the "axial canal" (*g*) previously described as passing upwards towards the oral pole, and may be traced along its whole length (generally more or less imbedded in its wall) to the point at which that canal subdivides into the five subtentacular canals which underlie the radial furrows of the disk. Here the axial cord appears to spread out into a plexus which surrounds the mouth; and this plexus is continued towards the periphery of the disk underneath the radial and brachial canals, every one of which usually has a cord running along each of its margins, connected by transverse branches with the cord of the opposite side. At or near the margin of the disk the two cords of each brachial canal seem to coalesce into a single one; and this runs onwards between the subtentacular and the cœliac canal of the arm (as shown at *gr*, fig. 6), giving off branches which pass into the sexual pinnules; and these branches are continuous with the testes or ovaries which these pinnules contain.

Hence it would appear that this "axial cord" is (in part, at least) a *generative rachis*, furnishing the germs which are to be developed into the proper sexual products; and this view I find to be confirmed by minute examination of its structure. At the point at which it dilates into the cavity of the ovary, it is clearly a tube containing minute corpuscles of about 1-3000th of an inch in diameter; and from these corpuscles to complete ova every stage can be traced. Following the cord backwards towards the plexus of the disk, I find it still to possess the same tubular wall and granular contents; in the plexus itself the cavity with its granular contents bears a smaller proportion to the thickness of the tubular wall; but the "axial prolongation," from which I believe this plexus to arise, often seems at the period of generative activity to be almost made up of such corpuscles.

I confess that I have not yet been able to trace the absolute continuity of the generative plexus of the disk with the axial cord of the adult *Antedon*, the dissection of the parts around the mouth being made very difficult by the quantity of loose connective tissue which forms the annular lip. The termination of the axial prolongation and the origin of the plexus in the same locality obviously point to such continuity; but

I shall show it to be almost unmistakably established by the history of embryonic development, at a certain stage of which the subdivision of the axial prolongation (*ax*, fig. 11) into diverging branches, of which one passes to each ray, is very distinctly traceable.

Arms.

Each Arm is composed of a linear series of calcareous segments, connected with each other by muscles and elastic ligaments, in the manner described in my former Memoir, the muscles being all *flexor*, whilst the ligaments are *extensor*. Thus when the muscles (of which a pair intervenes between each segment and its proximal and distal segments, except where two segments are connected by a syzygy) are called into contraction the arm is coiled up spirally like a watch-spring, whilst when the muscles relax it is straightened out again by the elasticity of the ligaments. —What may be called the *centrum* of every one of the calcareous segments is perforated by a circular foramen (*a a*, fig. 6); and the linear succession of these foramina forms a canal, which is occupied by a cord of protoplasmic substance (*b*) given off from the circlet contained within the first radials, which circlet (as already described) is formed by the lateral inosculation of the five radial cords (*l*, *m*, fig. 3) given off from the five-chambered organ (*g*) contained within the centro-dorsal basin. I have occasionally found, in transverse sections of decalcified arms (especially in *Antedon celticus*), pairs of branches given off from this "axial cord" at the junction of the segments to ramify upon the muscles; and it was this anatomical fact which suggested to me that the "axial cord" has really the function of a *nerve*, although not possessing its characteristic structure, and that the five-chambered organ must consequently be a nervous centre. That the cord which was supposed by Müller to be a nerve has an altogether different function, was stated in my previous Paper (§ 19), on the basis of the connexion I had even then demonstrated between that cord and the generative organs developed in the pinnules. And the nerve-function which I then, on anatomical grounds alone, attributed to the axial cord has been since completely borne out by the experiment to be presently cited.

Along the upper or oral face of the succession of calcareous segments with its intervening muscles there lies a single large canal (*cc*, fig. 6) occupying the whole breadth of each arm; this is the *cœliac* canal already spoken of as an extension of the lower part of the *cœlom* or perivisceral cavity (*cc*, fig. 12). Enclosed on either side by the perisome, it is shut in at the top by a transverse partition that separates it from the double subtentacular canal (*stc*, *stc*, fig. 6) which overlies it. This double canal is virtually single; for the vertical partition which divides it has large irregular openings (fig. 7), which allow a free communication between the two lateral halves*. Where this vertical partition joins the hori-

* In some species of *Antedon* this canal is actually as well as virtually single.

zontal partition separating the cœliac from the subtentacular canals, a longitudinal passage is left (which may be called the genital canal), in which lies what I have shown to be the generative *rachis* (fig. 6, *gr*), as Prof. Semper independently discovered. Where, again, this vertical partition joins the thickened layer of perisome which forms the floor of the inter-tentacular groove, there is a small circular canal (overlooked by Müller and every other anatomist), which is the real *tentacular* canal (*tc*, figs. 6, 8, 9), its continuity with the interior of the tentacles being very distinctly visible both in transverse and in longitudinal sections. The latter show a single oval orifice (*oo*, fig. 9) opening out of the tentacular canal for each group of three tentacles.

The perisome covering the oral surface of each arm exhibits a continuation of the brachial furrow formed by the divarication of the radial furrow of the oral disk, each side of this furrow being bounded, as in the disk, by successive groups of tentacles, and by an elevated fold of the perisome, scolloped at its edge so as to form a row of minute valvules, like those of the oral disk, beyond which, when the tentacles are extended, they project considerably, but within which they may be withdrawn, so that the two folds may close down, the valvules meeting in a sinuous line so as completely to cover the furrow.—The floor of the furrow is formed by the peculiar layer which, as already stated, I regard as a columnar epithelium; its free surface I believe to be clothed with minute cilia, the direction of whose movement is from the periphery towards the centre; there are, however, no cilia on the tentacles. These points, correctly stated by M. Edmund Perrier, I had worked out soon after the publication of my previous Paper.

Pinnules.—Every segment of the arms bears a pinnule; and the pinnules are disposed alternately along the two sides of each arm. Their calcareous segments are united by ligaments alone; but each centrum (*a*, figs. 8, 9) is perforated as in the arm, and contains a branch (*b*) of its axial cord. On the oral face of the succession of calcareous segments there lies an extension (*cc*, figs. 8, 9) of the *cœliac* canal of the arm; and immediately above this, in the barren pinnules, lies a single *subtentacular* canal coming off from the lateral division of the double canal of the arm which belongs to the side that bears the pinnule. In the thickness of the horizontal partition between these two canals there is a passage left by a separation of their walls, in which lies a lateral branch of the generative *rachis*. The true *tentacular* canal (*tc*, figs. 8, 9) lies, as in the arms, along the oral face of the subtentacular canal. The first pinnules of each arm, however, are differentiated from the rest by the absence of tentacles, and likewise by the greater number and closer setting of the peculiar sacculi (*ss*, figs. 6, 8) contained in the perisomal folds which bound the radial furrow.

When the tumefaction of a pinnule shows either the testis or the ovary to be developed in it, this organ is found to lie between the cœliac and

the subtentacular canal, completely separating the one from the other (figs. 6, 8); and it was this correspondence of position which first suggested to me the real nature of Müller's "nerve." On tracing the testis or ovary to the base of the pinnule, I clearly made it out to have the same relation to the lateral branch of the generative *rachis* of the arm (*h*, fig. 9) as the currants forming a bunch have to the stalk that bears them; and if I am correct in deriving the generative rachis from the "axial prolongations," it may be considered originally to spring from the Crinoid Axis itself.

Towards the extremities of the pinnules, especially in those that contain no generative organs, the horizontal partition between the *cœliac* and *subtentacular* canals thins away, and at last becomes obsolete; so that at the periphery of this canal-system there seems to be as free a communication between the two sets of canals as there is between the arteries and veins of the higher animals through the capillary plexus. And, for reasons to be presently given, I feel strongly inclined to believe that a regular circulation is carried on through them, the nutritive fluid being transmitted through one set of canals from centre to periphery, then passing into the other, and being conveyed by it back from periphery to centre.

Physiology.

Ingestion of Food.—That the food of *Antedon* consists, not of the large bodies grasped and swallowed by ordinary Starfish, but of minute and even microscopic organisms, and that the so-called "tentacles" are entirely destitute of prehensile power, was long since affirmed by Dujardin on the basis of observation of the habits of the living animal and of microscopic examination of the matters ejected from the vent. These statements are entirely borne out by my own careful observation of the actions of the brachial and tentacular apparatus, alike in the Pentacrinoid and in the adult condition, and by the microscopic examination I have repeatedly made of the contents of the alimentary canal. These consist of minute Entomostraca, Diatoms, spores of Algæ, &c., but especially, in my Lamlash specimens, of *Peridinium tripos* (Ehr.), which was usually very abundant in that locality. A powerful indraught current towards the mouth is maintained by the action of the large cilia that fringe the villous folds of the alimentary canal; but this does not extend to any considerable distance; and it is clear that minute particles are transmitted from the peripheral extremities of the arms and pinnules, along the brachial furrows and the radial furrows of the disk, to the neighbourhood of the mouth, where they come within the reach of the oral indraught. This I have repeatedly seen when I have had young Pentacrinoids alive under the microscope; and although I have been prevented, by the peculiarity of their position, from detecting the cilia to which the transmission is attributable, I can scarcely doubt that they belong to the epithelial floor of the furrows. And when I have detached

small pieces of the soft parts from the arms of the living adult, I have found currents to be produced in the water surrounding them, which could only be accounted for by ciliary action. Thus the brachial apparatus may be regarded, in the first place, as an extended food-trap.

It may be here added that my examination of various types of existing *Pentacrini* enables me to affirm that they are nourished in exactly the same manner, their brachial and digestive apparatus being constructed upon precisely the same plan as that of *Antedon*, and the contents of the alimentary canal being of the like nature. And this renders it probable that not only the *Pentacrini* of the Mesozoic period, but the entire series of *Crinoids* extending through the whole range of geological time, from the "primordial zone" of Barrande to the present epoch, obtained their food after the like fashion.

In the thickened disk which surrounds the mouth, formed at the junction of the perisome of the oral disk with the wall of the alimentary canal, I have detected a series of cæcal tubuli opening into the commencement or œsophageal portion of the alimentary canal; these may have a *salivary* function. And the peculiar gland-like character of the plicated portion of the wall of the inner side of the horizontal coil of the alimentary canal seems to render it probable that it performs the function of a *liver*.

Circulating and Respiratory Apparatus.—It has been shown that the true "tentacular" canals constitute a system entirely distinct in the adult from the general canal-system of the arms, although derived like it, in the first instance, from the perivisceral cavity, and that there is no proper oral ring which can be regarded as the centre of the radiating tentacular canal. As it has also been shown that the so-called "tentacles" have no share whatever in the ingestion of food, the question arises, what is their function in the economy of the animal? I am disposed to think that they are homologous with the tentacular fringe surrounding the mouth of the *Holothurida*, and with the "respiratory tubes" of the *Asterida* and *Echinida*, and that they constitute a special respiratory apparatus, serving for the aëration of a fluid that may be regarded, like the red blood of a *Terebella*, as not so much nutritive as respiratory*. It is no objection to this view that the tentacles of *Antedon* are not ciliated on their surface; for this is true also of the branchial tufts of *Terebella* and other *Annelids* having a double respiratory apparatus, one for the red blood, and the other for the "chylaqueous" fluid. Certain it is that *Antedon* is more dependent than Echinoderms generally upon the perfect aëration of its fluid, as it soon dies in water that is not kept in a state of tolerable purity, though *Ophiuræ* and *Ophiocomæ* may thrive in it.

* It is stated by M. Edmund Perrier that distinct muscular fibres are traceable in the walls of the tentacles; and these may produce a sort of vermicular contraction by which the fluid of this canal-system is kept in movement.

It has further been shown that, besides the tentacular canal-system, each arm and pinnule contains two canals, one superposed on the other, communicating at the termination of the pinnules, and that while the lower or *cœliac* canals open directly into the deeper portion of the cœlom or perivisceral cavity, the upper or *subtentacular*, passing inwards as the radial canals of the oral disk, become continuous with the upper part of the "axial canal," which opens at its lower end into the deepest part of the cœlom. Thus a complete continuity, alike central and peripherâl, is established throughout the whole of this space; and the central canal also receives what may be termed the "mesenteric sinuses" proceeding from the plications of the internal wall of the alimentary cavity. Thus it seems probable that the products of digestion, except such as may transude directly through the double wall of the alimentary canal into the cœlom, are collected into these mesenteric sinuses, and by them conveyed into the axial canal, and that from this centre the nutritive fluid is circulated throughout the double system of canals, passing from one to the other, centrally through the axial canal, and peripherally at the extremities of the pinnules. I have distinctly seen a movement of granular fluid in one of the canals of the arm of a Pentacrinoid, proceeding from the extremity towards the centre; and although I was unable to distinguish with certainty in which of the canals it took place, my impression is that it was the cœliac. If this be so, the *subtentacular* canals constitute the *arterial* or distributive, and the *cœliac* canals the *venous* or collective, system. Now as the axial canal is bounded by a columella strengthened by the piling-up of calcareous plates, its walls can scarcely be supposed to have any contractile power; whilst, on the other hand, as the surface of the peritoneum lining the cœlom is ciliated in other Echinoderms, it may be presumed to be so in *Antedon*: and thus we may fairly surmise that the circulation is kept up by ciliary movement. —If sea-water be admitted, as I believe it to be, through the ciliated funnels of the oral perisome, into the cavity of the cœlom, the circulating fluid will correspond in its mixed character to the "chylaqueous" fluid of many aquatic Invertebrata.

One important office of this circulation will obviously be to supply nutritive material for the periodical development of the sexual apparatus; and no arrangement could be conceived more conducive to such a purpose. For in the pinnules, whose turgidity indicates the enlargement of the generative *rachis* into testes or ovaries (as the case may be), these organs (as shown in figs. 8, 9) lie between the two thin-walled canals, so that they can readily draw nutrient fluid alike from the going and from the returning current. It can scarcely be doubted that the "chylaqueous" fluid is aërated during its transmission through the canals of the arms and pinnules, particularly as the clothing of very minute cilia which I have detected on the dorsal side of the arms will serve to renew the stratum of water in contact with them.

Thus we are also to regard the arms and pinnules in the light of a *respiratory* apparatus, an interchange of gases between the contents of the canals and the surrounding medium being promoted by the subdivision of the canals and the consequent extension of their surface.

Nervo-muscular Apparatus.—In the First Part of my Memoir I described the manner in which the contraction of the pairs of muscles intervening between the vertical lamellæ rising from the oral faces of the successive calcareous segments of each arm coils it up into a spiral, the uncoiling being produced, when the muscles relax, by the elasticity of the ligaments interposed between the segments near their dorsal margins. The coiling and uncoiling often take place through the whole length of the arm, with a quickness and consentaneousness which has no parallel in the comparatively sluggish and limited movements of other Echinoderms; and while a single arm may be made to coil up by irritating one of its pinnules, the whole circlet of arms closes together when an irritation is applied to the pinnules which arch over the mouth, an act which affords a strong indication of the "internuncial" action of a definite nervous system. The anatomical considerations already specified having led me to the conclusion that the radial cords which pass through the calcareous segments of the arms are really nerve-trunks, and that the five-chambered organ in the centro-dorsal basin is their centre, I put their character to the following experimental test, when visiting Oban in the autumn of 1867:—Having completely eviscerated a living specimen, so that nothing was left but the calyx and arms, with the centro-dorsal basin and its contents, I passed a needle down through the canal left at the base of the calyx between the central faces of the first radials, so as to irritate the quinquelocular organ beneath; all the ten arms then suddenly and consentaneously closed up. On the withdrawal of the needle, the arms gradually straightened themselves again, and again coiled up as before when the irritation of the central organ was renewed. I am at a loss to see in what respect the evidence thus afforded that this organ is functionally a nerve-centre, and that the radial cords are nerve-trunks, is less cogent than that which we draw from the contraction of the limbs of a Vertebrate animal when we irritate the segment of the spinal cord which gives off their nerves. The chief difficulty in assigning to them such a function arises from their want of the histological characters of nerves. The radial cords, hardened in strong spirit, may be torn into fibrils of extreme minuteness; but, so far as I have yet been able to ascertain, these fibrils have a homogeneous protoplasmic composition. This absence of differentiation may, as it seems to me, be related to the fact that as the muscles are all flexors, the nerves have only one function to perform, and that there is consequently no need of the insulation which they require where nerve-fibres of very different functions are bound up in the same sheath.

The curious little saccular organs (*s s*, figs. 6, 8) which lie at intervals

along the outside of the ridges that border the tentacular furrow in the arms and pinnules, and which, by their peculiar property of attracting the colouring-matter given off after death by other parts of the body, become the well-known "red spots," have long been a puzzle to students of *Antedon*. I have long been myself inclined to regard them as Sensory organs, my surmise being founded on the fact that in the oral pinnules, which have no tentacular apparatus, but which are much more irritable (*i. e.* more susceptible of impressions which call forth contraction of the arms) than the tentaculiferous pinnules, these sacculi are crowded together so as to form two continuous rows*.

Development.

In the earliest stage at which I have been hitherto able to study the Pentacrinoid larva (which may be designated as "Allman's stage†"), the calyx rather resembles an inverted bell than a shallow basin, its lower part being supported by the five basals, whilst its upper is surrounded by the five incipient first radials which alternate with them. Alternating in position with the five first radials, and at this stage resting immediately upon them, are five oral plates, somewhat triangular in form, enclosed in valvular folds of the delicate perisome which forms the general investment of the body. These oral valves, when inclined towards each other, form a sort of five-sided pyramid, which completely covers in the oral disk; but when opened out they surround it like the expanded petals of a flower. Immediately within the oral valves is a thin elevated lip, from which spring the oral tentacles; and the wide mouth, leading into a funnel-shaped œsophagus, occupies the whole of the area surrounded by this lip. A vertical section of the calyx in this stage shows the gastric sac loosely suspended in the perivisceral cavity or *cœlom* (*pv*, fig. 10), with the inner wall of which, however, the outer wall of the gastric sac is connected by scattered threads and lamellæ of connective tissue. And it is very distinctly seen that the circular lip is formed by an annular plication of the bounding membrane of the perivisceral cavity, a space being left between the two folds, which constitutes the original tentacular or ring-canal, *rc*. Hence this tentacular canal is clearly a derivative of the *cœlom*, the only separation between them at this stage consisting in a circlet of threads of connective tissue, which passes between the inner and outer folds of the lip. The increased development of this connective tissue subsequently constitutes a partition that cuts off the oral ring from the *cœlom*, and finally breaks up the canal itself into an irregular areolation.

The gastric sac at this stage is elongated horizontally into a form

* They have been carefully studied by M. Edmund Perrier (*loc. cit.*), who has corrected (as I had long since privately done) the mistake into which Prof. Wyville Thomson fell in regarding the corpuscles they contain as calcareous, but has not thrown any further light on their function.

† See his Memoir in the Edinb. Trans. Roy. Soc. vol. xxiii. (1861), p. 241.

somewhat resembling that of the human stomach, having a "large end" into which the funnel-shaped œsophagus opens obliquely, and a "small end" with a cæcal termination (*an*, fig. 10), which is the original intestine. To the middle of this gastric sac, in sections which exhibit it *in situ*, the "axial prolongation" may be distinctly seen passing up from the base of the calyx. The wall of the gastric sac is everywhere thick, and is chiefly composed of a yellow substance which appears to consist of a layer of columnar epithelial cells, the free surface of which layer is clothed with cilia.

The further development of the alimentary canal consists, in the first place, in the prolongation of the intestinal extension of the gastric sac—this prolongation at first taking place horizontally, so that the intestine coils round the stomach in the space left for it by the enlargement of the calyx. Later on, as the second and third radials are developed and the cavity of the calyx opens out, while the circlet of oral valves undergoes very little enlargement, there comes to be a space between the outside of that circlet and the inside of the circlet of incipient arms; at one point of this space a projection of the perisome shows itself, enclosing a single thin oval calcareous plate; and towards this projection the cæcal termination of the elongating intestine directs itself upwards. At last it reaches the prominence of the oral disk, and opens upon its surface, forming the projecting vent.—The manner in which the axial canal is formed by the gradual limitation of the space left by the coiling of the intestine round the stomach (*al*, fig. 11) is shown very clearly in this and the succeeding stages; and I have been fortunate enough to trace the axial prolongation (*ax*) upwards through this space, from the base of the calyx to its subdivision, by the side of the œsophageal funnel, into five radial branches.

The extension of the oral ring into the radial and brachial tentacular canals having been minutely described by Prof. Wyville Thomson, I need not go over the same ground; but I have now to speak of the origin of the subtentacular and cœliac canals.

From the time when the intestinal coil is formed, and its anal termination opens on the surface of the disk, the growth of the alimentary canal goes on at a greater rate than the enlargement of the calyx; and the consequence is that the marginal portion of the intestine comes into such close contact with the lining of the calyx, as to divide the cœlom into an upper or oral and a lower or dorsal portion* (fig. 12); and this division is completed by the membranous fold, *mf*. From each portion there passes a sort of digitate extension into every ray, each extension having its own lining membrane. The communication of the lower extension,

* This has been distinctly recognized by Metschnikoff, who also has pointed out (what had long since occurred to myself) that the relation of the visceral and tentacular apparatus to the two divisions of the perivisceral cavity remarkably corresponds with that which prevails in many Polyzoa.

forming the cœliac canal (*cc*, fig. 12) of the rays and arms, with the ventral division of the cœlom always remains freely open; but that of the upper or oral extension forming the subtentacular canals (*stc*) of the rays and arms, with the oral division of the cœlom itself, is gradually limited by the enlargement of the visceral mass, and by the formation of adhesions between its upper surface and the under surface of the oral disk; so that, as the vertical communication between the upper and lower divisions of the cœlom becomes gradually narrowed into the "axial canal," so the oral portion of the cœlom may be said to become gradually narrowed into the subtentacular canals of the disk.

The principal changes of note which occur in the further development of the visceral mass consist in the progressive infolding of the wall of the alimentary canal on the central side of the tube, so as to form the gland-like projection into its cavity; the development of the calcareous disks in the inner or mucous layer of that wall, the piling-up of which in its infolded portions constitutes the "columella;" the separation of the outer or peritoneal layer from the mucous, forming a space which is crossed by multitudinous threads and lamellæ of connective tissue; the narrowing of the spaces formed by the infolding of the walls of the alimentary tube into the mesenteric canals which open into the axial canal; and, generally, the development, in various parts, of a large quantity of connective tissue, which traverses what would otherwise be vacuities, and gives compactness to the whole "visceral mass."

The mode of development of the peripheral portion of the summit of the original Crinoidal axis into the quinquelocular organ contained within the centro-dorsal plate has been already noticed; and as I described in my former Memoir the very curious manner in which its radial cords, which at first lie on the upper or ventral side of the basal plates, finally come to lie on the lower or dorsal side of the "rosette" formed by their metamorphosis, I need not here repeat the history.

EXPLANATION OF THE PLATES.

Plate 8.

Fig. 1. Horizontal Section of the Visceral mass of *Antedon rosaceus* (after decalcification of the skeleton), laying open the intestinal coil:—*a*, termination of the oblique or œsophageal portion in the horizontal or intestinal portion *b*, *c*, which forms a *cul-de-sac* at *d*, where it abruptly bends upwards to form the projecting vent; at *g* is seen the axial canal, surrounded by the columella formed by the infolding and duplication of the intestinal wall; *f*, connective tissue and interspace-system, shown at *e* to be an extension of the space between the two lamellæ of the intestinal wall.

Fig. 2. Vertical Section of the Calyx:—*a*, mouth, surrounded by oral ring, and surmounted by the two tentaculiferous lobes *m m*; at *b* is seen the oblique or œsophageal portion of the alimentary canal, the horizontal or intestinal coil of which is transversely divided at *c* and *d*, showing in section the corrugations of its double wall, the internal surface of which is covered by a thick (hepatic?) epithelial layer, *e*, *f*. At *g* is seen the lower part of the axial

canal, containing a portion of the axial prolongation *h*. The middle part of this canal communicates on either side with the interspace-system formed by the infolding of the double wall of the alimentary canal; and at *l* is seen in transverse section, opening into the summit of the axial canal, one of the radial subtentacular canals of the ventral disk. On the other side of the mouth are seen two of the brachial subtentacular canals, one of them transversely divided at *i*, and the other obliquely divided at *k*, about to coalesce into a radial canal which passes round the œsophagus to open into the axial canal.—This section has not laid open the quinquelocular organ in the centro-dorsal basin; but from its lower or dorsal margin several small cords, *l*, are seen to pass off to enter the dorsal cirrhi.

Fig. 3. Vertical Section of the Calyx, through a different plane from the preceding:—*a*, *b*, *c*, *d*, *e*, *f* as in the last figure; *g*, quinquelocular organ; *h*, lower part of the axial prolongation, springing from the central axis of the quinquelocular organ, and passing behind one of the extensions of the glandular reduplication, to reappear above it at *h′*, proceeding to the circular lip seen in section at *i*; at *k* is shown the mass of connective tissue with its interspace-system lying between the duplications of the intestinal wall that form the columella; *l*, *m*, two of the axial (nerve?) cords proceeding to the rays from the upper or ventral margin of the quinquelocular organ.

Fig. 4. Transverse Section of the Quinquelocular organ, viewed from its upper or ventral aspect:—*a*, central axis formed by a prolongation of the axis of the Crinoidal stem; *b*, *b*, dissepiments forming five ventricular cavities; *c*, *c*, one of the axial verticils sending off cords that seem to pass through the peripheral wall to proceed to the dorsal cirrhi; *d*, *d*, apertures by which the five ventricular cavities communicate with the perivisceral space.

Fig. 5. Vertical Section of the Quinquelocular organ, showing the division of its upper or ventral portion *b* into chambers, and the occupation of its lower or dorsal portion *a* by a succession of axial verticils giving off cords to the cirrhi.

Plate 9.

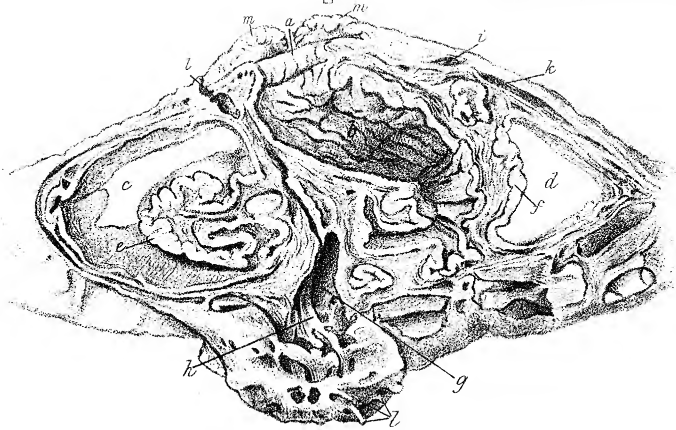
Fig. 6. Transverse Section of decalcified Arm:—*a*, *a*, organic basis of calcareous segment; *b*, solid axial (nerve?) cord proceeding from quinquelocular organ; *m*, *m*, muscles; *cc*, cœliac canal; *gr*, tubular genital rachis (the nerve of Müller), lying in its genital canal; *stc*, the two subtentacular canals (the tentacular canals of Müller), which virtually form a single canal, the partition between them being cribriform, as shown in fig. 7; *tc*, the true tentacular canal, giving off alternating lateral branches to the tentacular apparatus and the crescentic folds, at the base of which lie the saccular (sensory?) organs *s s*.

Fig. 7. Longitudinal Section of the ventral portion of the Arm:—*cc*, cœliac canal, giving off at *d d* lateral branches to the pinnules; *stc*, subtentacular canal, divided from its fellow by cribriform partition. The section has not laid open the true tentacular canal; but the orifices by which it communicates with the tentacular system of the near side are seen at *t t*, and those leading into the bases of the groups of tentacles of the off side are seen at *t′ t′*.

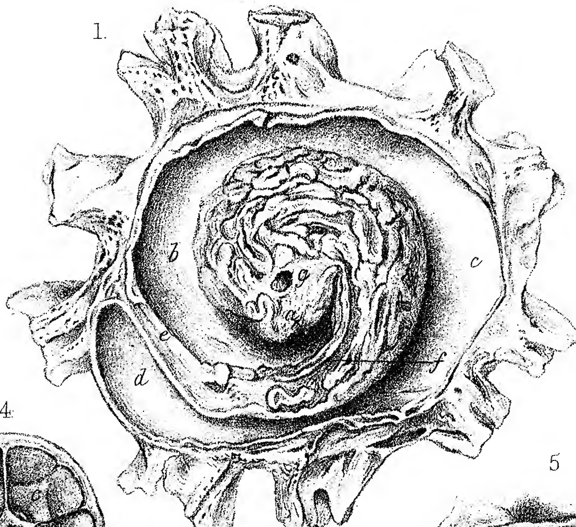
Fig. 8. Transverse Section of decalcified Spermatigerous Pinnule:—*a*, organic basis of calcareous segment; *b*, axial cord; *cc*, cœliac canal; *t*, testis, lying within a dilatation of the genital canal *gc*, and developed (like the ovary shown in fig. 9) from a peduncle given off from the genital rachis; *stc*, single subtentacular canal; *tc*, true tentacular canal; *s s*, saccular (sensory?) organs.

Fig. 9. Longitudinal Section of decalcified Ovigerous Pinnule:—*a a*, organic basis of

2

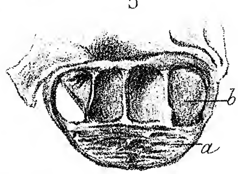


1.



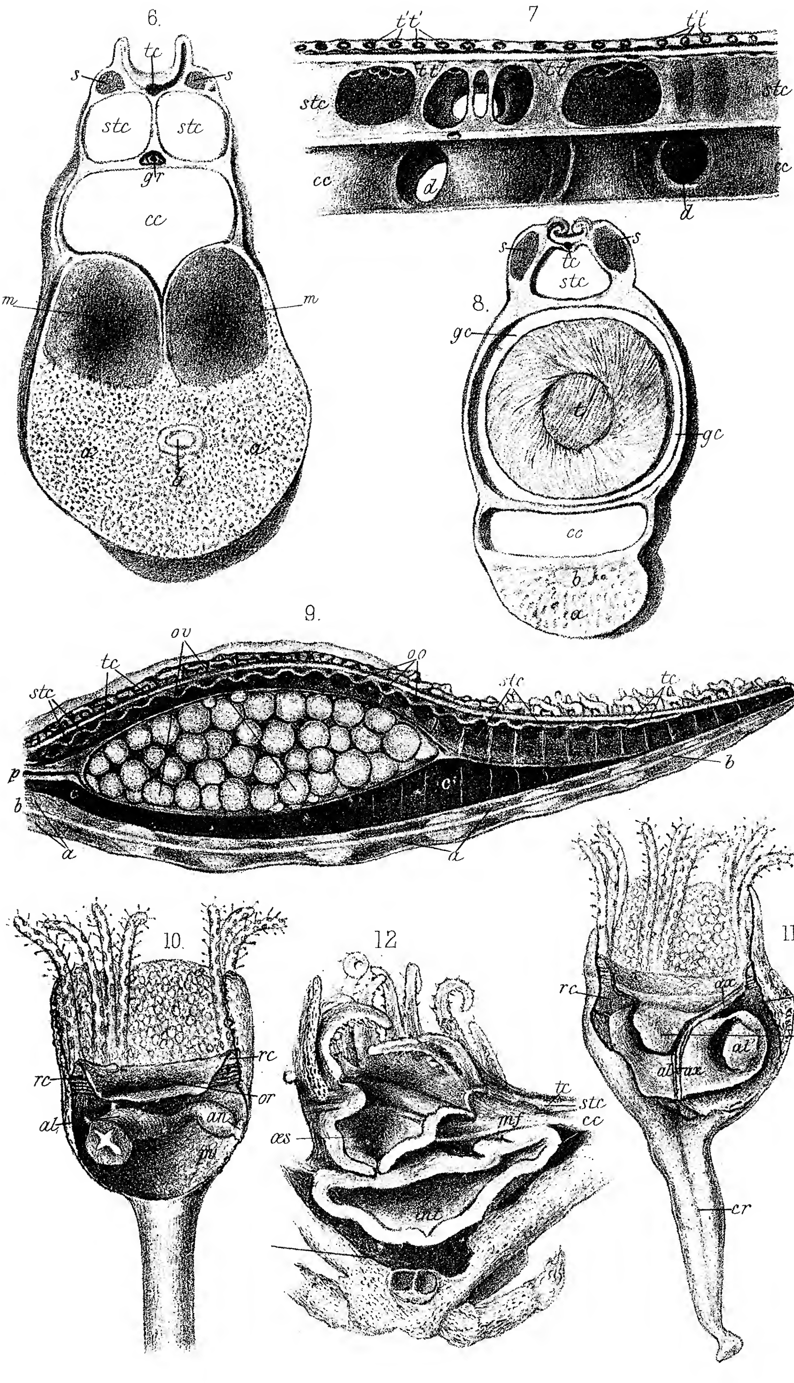
4

5



3

A.T. Hollick del.



A. T. Hollick. del.

calcareous segments; *b*, axial cord; *c c*, cœliac canal, extending to near the extremity of the pinnule; *ov*, ovary filling the dilatation of the genital canal, and developed from the peduncle *p* given off from the genital rachis of the arm; *stc*, subtentacular canal; *tc*, true tentacular canal, with its orifices, *o o*, leading to the tentacular apparatus.

Fig. 10. Vertical Section of a very young Pentacrinoid, showing a portion of the Alimentary canal *al*, hanging freely in the large perivisceral space *pv*, and the formation of the ring-canal *rc* from which the tentacles proceed, by the marking-off of the portion of the space included in the fold of the oral disk *or*, by transverse threads of connective tissue. At *an* is seen the cæcal termination of the intestine, not yet bending upwards to protrude as a vent.

Fig. 11. Vertical Section of a somewhat more advanced Pentacrinoid, in which the development of the Arms has not yet commenced, showing the enlargement of the Alimentary canal *al* divided transversely at *al'*, and the relative diminution of the perivisceral space; the crinoidal axis of the stem *cr* is seen to be prolonged upwards at *ax*, through the central space left within the intestinal coil, and to pass obliquely along the œsophageal portion *œs* of the canal towards the oral ring-canal, *rc*.

Fig. 12. Vertical Section of a Pentacrinoid in which the Arms and Dorsal Cirrhi have appeared:—the alimentary canal, of which *œs* is the œsophageal portion, and *int* the intestinal portion, now fills the perivisceral cavity more completely; and a membranous fold *mf* shows itself, which divides that cavity into a dorsal and a ventral portion. From the former proceeds the cœliac canal *cc*; from the latter the subtentacular canal *stc*; while the true tentacular canal *tc* proceeds from the oral ring-canal, which is still not blocked up by the cæcal tubuli and connective tissue that subsequently occupy it.

January 27, 1876.

Dr. J. DALTON HOOKER, C.B., President, in the Chair.

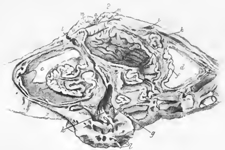
The Presents received were laid on the table, and thanks ordered for them.

The following Papers were read:—

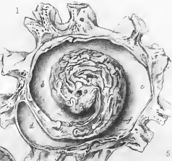
I. "On the Variations of the Daily Mean Horizontal Force of the Earth's Magnetism produced by the Sun's Rotation and the Moon's Synodical and Tropical Revolutions." By J. A. Broun, F.R.S. Received December 15, 1875.

(Abstract.)

The variations of daily mean horizontal force in the years 1844 and 1845 showed several well-marked oscillations, having periods of from 20 to 30 days, and amplitudes, in some cases, of more than one thousandth of the whole magnetic force. These oscillations were first attributed to lunar action; afterwards they were found more probably due to the sun's rotation on his axis. The disappearance of these oscillations in



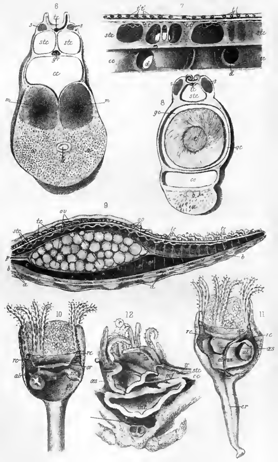
1



4

5

3


6
tc
s
stc
gr
cc
m
7
stc
tc
cc
d
8
stc
gc
cc
9
ov
go
tc
stc
p
b
a
d
10
rc
ab
or
12
mf
stc
rc
as
at
11
rc
at
as
cr